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BELLCOMM, INC.

SUBJECT: Supplemental Spacecraft Performance Calculations - Case 217

DATE: December 16, 1964

FROM: D. R. Valley

MEMORANDUM FOR FILE

This memorandum is a supplement to the Spacecraft Weight Performance Calculations memorandum dated November 25, 1964.

The attached equations for total spacecraft weight at injection, LEM separation weight, and LEM weight at lunar launch were originally worked out as a means of checking computer generated values for some of the spacecraft sensitivities presented in the November 25 memorandum. In addition to serving as a check, the equations readily provided the sensitivities of these three functions to the spacecraft weight losses due to the use of expendables during each of the mission phases. These particular sensitivities cannot readily be obtained by the computer program at the present time.

The three equations have additional value in clearly showing what parameters affect the sensitivities. The bracketed quantities in each term represent the sensitivity of the entire function to the weight component shown in front of each term. It can be readily seen for example, that the sensitivities to each of the various spacecraft weight components are dependent only on the ΔV budget and the engine performance parameters ($u = g_o I_{sp}$).

Although these equations appear somewhat cumbersome, they can serve as a quick and accurate means of evaluating the effect of various changes in spacecraft weights on overall spacecraft weight performance. It is only necessary to evaluate those terms involving changes from some reference condition by multiplying the amount of the change by the associated sensitivity. The algebraic summation of all the terms affected will provide the total change from the reference.

Evaluation of spacecraft weight figures reported each month would become a relatively simple matter since the number of items that change from month to month is usually small.

The equations presented here are not necessarily restricted to use in cases involving the same engine performance and ΔV budget. They are perfectly valid for variations in these parameters as well; however, their use is much more tedious since these parameters appear in so many of the terms in each of the equations. For example, to evaluate the effect of a change in ΔV required for the first translunar midcourse correction (ΔV_{16}) on the total spacecraft weight at injection, it would be necessary to compute and summarize values for 20 of the 21 terms in that equation.

To avoid classification of this memorandum, numerical values for bracketed terms of these equations based on the present engine performance and ΔV budget have not been included. Values for all terms except those involving expendables (EX_1 THRU EX_{17}) are available in the spacecraft sensitivities presented in the November 25 memorandum. The sensitivities to the weights of spacecraft expendables can be obtained by contacting the author.

2011-DRV-cms

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DEFINITION OF SYMBOLS

LA_F = FINAL WEIGHT OF LEM-ASCENT STAGE

LD_F = FINAL WEIGHT OF LEM-DESCENT STAGE

CSM_F = FINAL WEIGHT OF COMMAND & SERVICE MODULES

CREW = WEIGHT OF CREW & EQUIPMENT TRANSFERRED TO LEM

$u_1 = g_0 I_{sp}$ OF SERVICE MODULE ENGINE
$u_2 = g_0 I_{sp}$ OF LEM-RCS ENGINES
$u_3 = g_0 I_{sp}$ OF LEM-ASCENT ENGINE
$u_4 = g_0 I_{sp}$ OF LEM-DESCENT ENGINE

ΔV_1 = ΔV FOR TRANS-EARTH MIDCOURSE CORRECTION #3
ΔV_2 = " " " " " " #2
ΔV_3 = " " " " " " #1
ΔV_4 = " " TRANS-EARTH INJECTION
ΔV_5 = " " LEM RESCUE
ΔV_6 = " " RENDEZVOUS AND DOCKING
ΔV_7 = " " LEM MIDCOURSE CORRECTION
ΔV_8 = " " LUNAR LAUNCH
ΔV_9 = " " TRANSLATION AND TOUCHDOWN
ΔV_{10} = " " DESCENT TO 200 FEET
ΔV_{11} = " " TRANSFER ORBIT INSERTION
ΔV_{12} = " " LEM SEPARATION
ΔV_{13} = " " LUNAR ORBIT INSERTION
ΔV_{14} = " " TRANS-LUNAR MIDCOURSE CORRECTION #3
ΔV_{15} = " " " " " " #2
ΔV_{16} = " " " " " " #1

EX_1 = EXPENDABLES USED BETWEEN ENTRY AND TRANS-EARTH MIDCOURSE CORRECTION #3
EX_2 = " " " TRANS-EARTH MCC #3 AND MCC #2
EX_3 = " " " " " MCC #2 AND MCC #1
EX_4 = " " " " " MCC #1 AND TRANS-EARTH INJECTION
EX_5 = " " BY CSM FROM LEM SEPARATION UNTIL LEM RETURN
EX_6 = " " BY LEM DURING RENDEZVOUS AND DOCKING
EX_7 = " " BY LEM BETWEEN LEM MCC AND RENDEZVOUS AND DOCKING
EX_8 = " " BY LEM BETWEEN LUNAR LAUNCH AND LEM MCC
EX_9 = " " BY LEM ON LUNAR SURFACE
EX_{10} = " " BY LEM BETWEEN TRANSLATION & TOUCHDOWN AND DESCENT
EX_{11} = " " BY LEM BETWEEN DESCENT AND TRANSFER ORBIT INSERTION
EX_{12} = " " BY LEM BETWEEN TRANSFER ORBIT INSERTION & LEM SEPARATION
EX_{13} = " " IN LUNAR ORBIT PRIOR TO LEM SEPARATION
EX_{14} = " " BETWEEN LUNAR ORBIT INSERTION AND TRANS-LUNAR MCC #3
EX_{15} = " " " TRANSLUNAR MCC #3 AND MCC #2
EX_{16} = " " " " MCC #2 " MCC #1
EX_{17} = " " " " MCC #1 " TRANSLUNAR INJECTION

LEM SEPARATION WEIGHT (INCLUDING CREW)

$$= LA_F \left[e^{\frac{\Delta V_6 + \Delta V_7 + \Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_8}{u_3}} \cdot e^{\frac{\Delta V_9 + \Delta V_{10} + \Delta V_{11}}{u_4}} \right]$$

$$+ LD_F \left[e^{\frac{\Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_9 + \Delta V_{10} + \Delta V_{11}}{u_4}} \right]$$

$$+ CREW \left[e^{\frac{\Delta V_6 + \Delta V_7 + \Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_8}{u_3}} \cdot e^{\frac{\Delta V_9 + \Delta V_{10} + \Delta V_{11}}{u_4}} \right]$$

$$+ EX_6 \left[e^{\frac{\Delta V_6 + \Delta V_7 + \Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_8}{u_3}} \cdot e^{\frac{\Delta V_9 + \Delta V_{10} + \Delta V_{11}}{u_4}} \right]$$

$$+ EX_7 \left[e^{\frac{\Delta V_7 + \Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_8}{u_3}} \cdot e^{\frac{\Delta V_9 + \Delta V_{10} + \Delta V_{11}}{u_4}} \right]$$

$$+ EX_8 \left[e^{\frac{\Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_8}{u_3}} \cdot e^{\frac{\Delta V_9 + \Delta V_{10} + \Delta V_{11}}{u_4}} \right]$$

$$+ EX_9 \left[e^{\frac{\Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_9 + \Delta V_{10} + \Delta V_{11}}{u_4}} \right]$$

$$+ EX_{10} \left[e^{\frac{\Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_{10} + \Delta V_{11}}{u_4}} \right]$$

$$+ EX_{11} \left[e^{\frac{\Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_{11}}{u_4}} \right]$$

$$+ EX_{12} \left[e^{\frac{\Delta V_{12}}{u_2}} \right]$$

LEM WEIGHT AT LUNAR LAUNCH (INCLUDING CREW)

$$= LA_F \left[e^{\frac{\Delta V_6 + \Delta V_7}{u_2}} \cdot e^{\frac{\Delta V_8}{u_3}} \right]$$

$$+ CREW \left[e^{\frac{\Delta V_6 + \Delta V_7}{u_2}} \cdot e^{\frac{\Delta V_8}{u_3}} \right]$$

$$+ EX_6 \left[e^{\frac{\Delta V_6 + \Delta V_7}{u_2}} \cdot e^{\frac{\Delta V_8}{u_3}} \right]$$

$$+ EX_7 \left[e^{\frac{\Delta V_7}{u_2}} \cdot e^{\frac{\Delta V_8}{u_3}} \right]$$

$$+ EX_8 \left[e^{\frac{\Delta V_8}{u_3}} \right]$$

TOTAL SPACECRAFT WEIGHT AT INJECTION (LESS ADAPTER)

$$\doteq LA_F \left[e^{\frac{\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \cdot e^{\frac{\Delta V_6+\Delta V_7+\Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_8}{u_3}} \cdot e^{\frac{\Delta V_9+\Delta V_{10}+\Delta V_{11}}{u_4}} \right]$$

$$+ LD_F \left[e^{\frac{\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \cdot e^{\frac{\Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_9+\Delta V_{10}+\Delta V_{11}}{u_4}} \right]$$

$$+ CSM_F \left[e^{\frac{\Delta V_1+\Delta V_2+\Delta V_3+\Delta V_4+\Delta V_5+\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \right]$$

$$+ CREW \left[e^{\frac{\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \left(e^{\frac{\Delta V_6+\Delta V_7+\Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_8}{u_3}} \cdot e^{\frac{\Delta V_9+\Delta V_{10}+\Delta V_{11}}{u_4}} + e^{\frac{\Delta V_1+\Delta V_2+\Delta V_3+\Delta V_4+\Delta V_5}{u_1}} - e^{\frac{\Delta V_5}{u_1}} \right) \right]$$

$$+ EX_1 \left[e^{\frac{\Delta V_1+\Delta V_2+\Delta V_3+\Delta V_4+\Delta V_5+\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \right]$$

$$+ EX_2 \left[e^{\frac{\Delta V_2+\Delta V_3+\Delta V_4+\Delta V_5+\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \right]$$

$$+ EX_3 \left[e^{\frac{\Delta V_3+\Delta V_4+\Delta V_5+\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \right]$$

$$+ EX_4 \left[e^{\frac{\Delta V_4+\Delta V_5+\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \right]$$

$$+ EX_5 \left[e^{\frac{\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \right]$$

$$+ EX_6 \left[e^{\frac{\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \cdot e^{\frac{\Delta V_6+\Delta V_7+\Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_8}{u_3}} \cdot e^{\frac{\Delta V_9+\Delta V_{10}+\Delta V_{11}}{u_4}} \right]$$

$$+ EX_7 \left[e^{\frac{\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \cdot e^{\frac{\Delta V_7+\Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_8}{u_3}} \cdot e^{\frac{\Delta V_9+\Delta V_{10}+\Delta V_{12}}{u_4}} \right]$$

$$+ EX_8 \left[e^{\frac{\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \cdot e^{\frac{\Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_8}{u_3}} \cdot e^{\frac{\Delta V_9+\Delta V_{10}+\Delta V_{11}}{u_4}} \right]$$

$$+ EX_9 \left[e^{\frac{\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \cdot e^{\frac{\Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_9+\Delta V_{10}+\Delta V_{11}}{u_4}} \right]$$

$$+ EX_{10} \left[e^{\frac{\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \cdot e^{\frac{\Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_{10}+\Delta V_{11}}{u_4}} \right]$$

$$+ EX_{11} \left[e^{\frac{\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \cdot e^{\frac{\Delta V_{12}}{u_2}} \cdot e^{\frac{\Delta V_{11}}{u_4}} \right]$$

$$+ EX_{12} \left[e^{\frac{\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \cdot e^{\frac{\Delta V_{12}}{u_2}} \right]$$

$$+ EX_{13} \left[e^{\frac{\Delta V_{13}+\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \right]$$

$$+ EX_{14} \left[e^{\frac{\Delta V_{14}+\Delta V_{15}+\Delta V_{16}}{u_1}} \right]$$

$$+ EX_{15} \left[e^{\frac{\Delta V_{15}+\Delta V_{16}}{u_1}} \right]$$

$$+ EX_{16} \left[e^{\frac{\Delta V_{16}}{u_1}} \right]$$

$$+ EX_{17}$$